

# Hydropower – Sustainable management of a renewable energy source

## Worldwide perspective & lessons learned in Switzerland

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ISTC 2017 – Almaty– November 3<sup>rd</sup> 2017

# **Global overview**

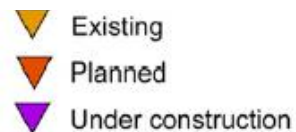
Importance of hydropower & possible impacts

# Overview global dams

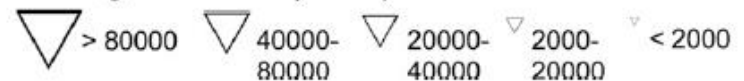
6374 Existing



Grill et al. (2015).  
*Environ. Res. Lett.*

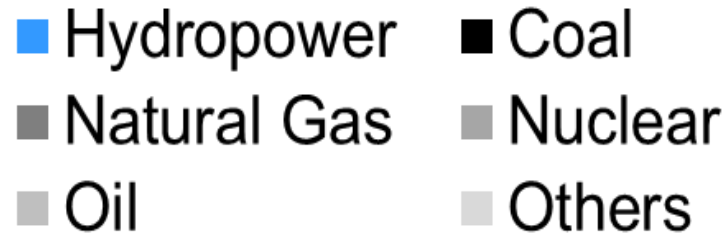


Storage volume (mcm)

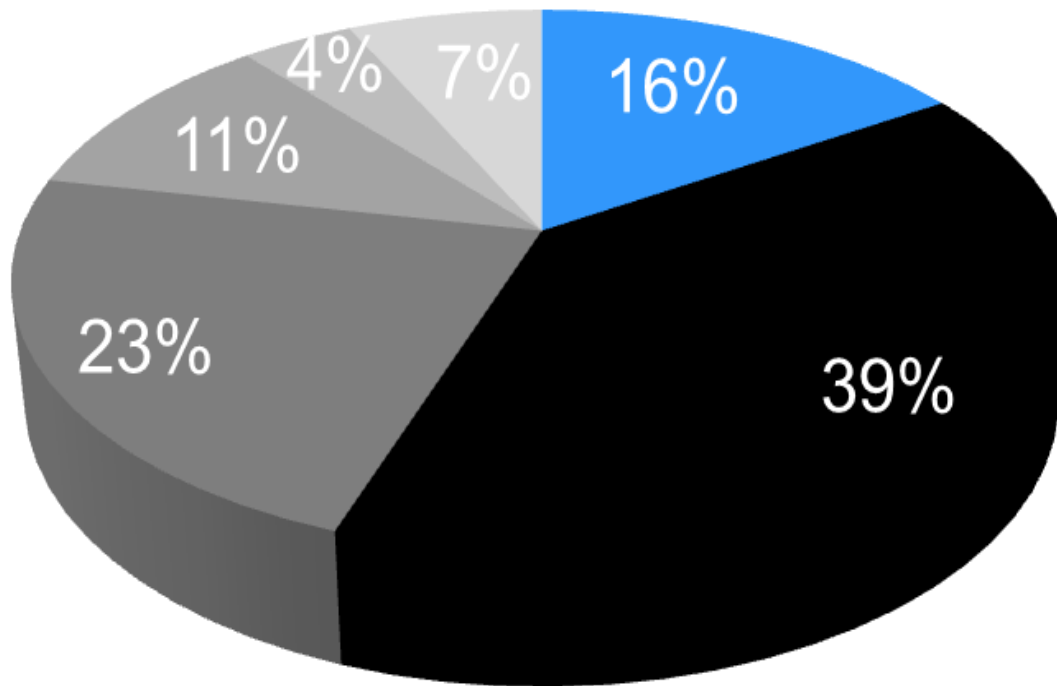


# Importance of hydropower plants

## World electricity generation



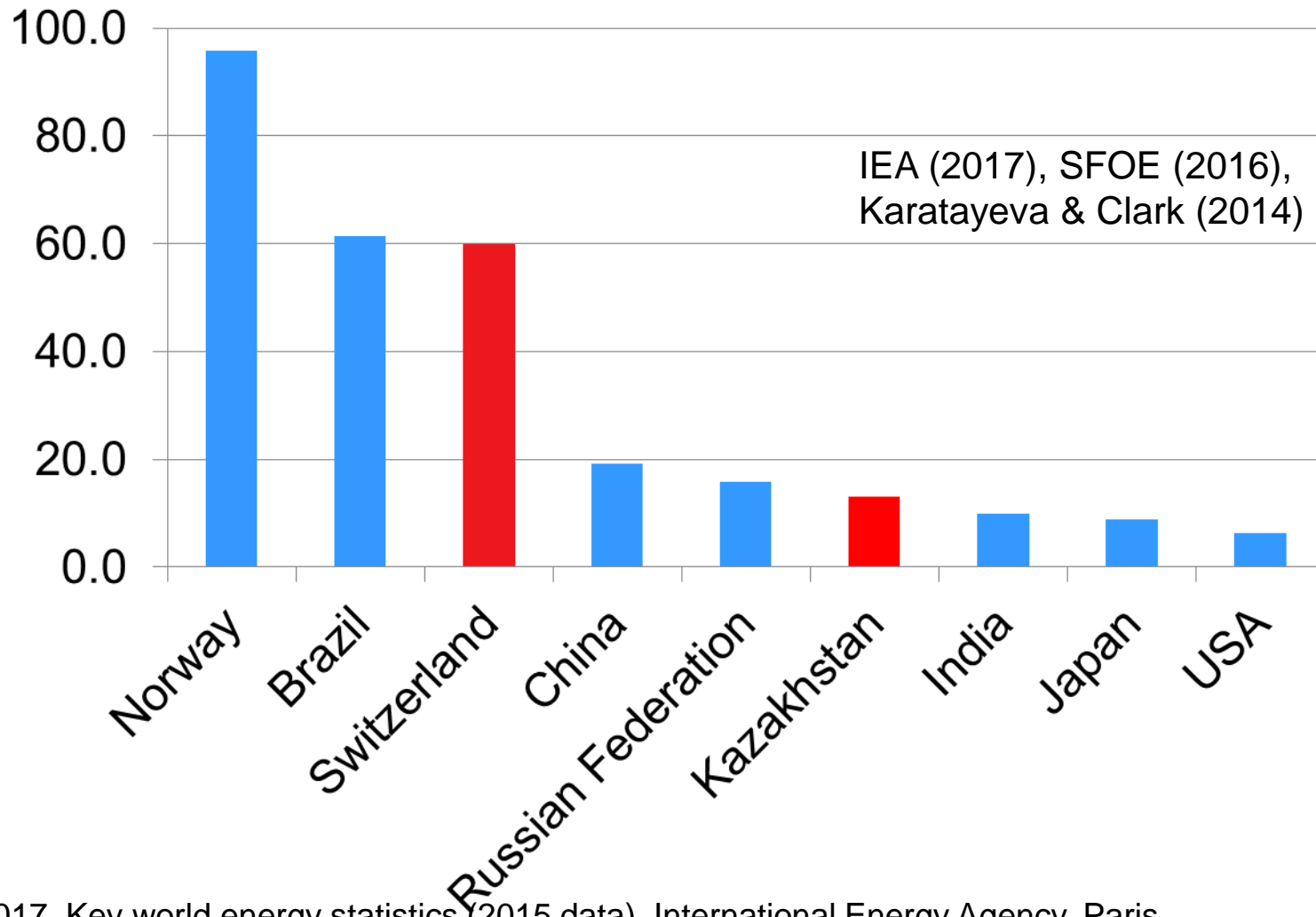
China: largest installed capacity (332 GW) and production (ca. 28.4% of world total)



IEA (2017)

# Importance of hydropower plants

## % hydro to total country electricity production



IEA 2017. Key world energy statistics (2015 data). International Energy Agency, Paris.

SFOE 2016. Schweizerische Elektrizitätsstatistik 2015 (2015 data). Swiss Federal Office of Energy, Berne.

Karatayeva & Clark 2014. Current energy resources in Kazakhstan and the future potential of renewables: A review. Energy Procedia 59: 97 – 104.

# Advantages & impacts of hydropower

## ■ Main possible advantages:

- Renewable energy source, almost CO<sub>2</sub>-neutral
- Excellent efficiency
- Rapid response to electricity demand (storage power plants)
- Carryover of electricity production from summer to winter (storage power plants)
- Jobs and money
- Flood protection (storage power plants)

## ■ Main possible impacts:

- Social (e.g. resettling people)
- Water use (e.g. agriculture, drinking water, etc.)
- Fragmentation
- Flow regulation: Reduction of flood, Residual flow & Hydropeaking
- Reduction of bedload dynamic

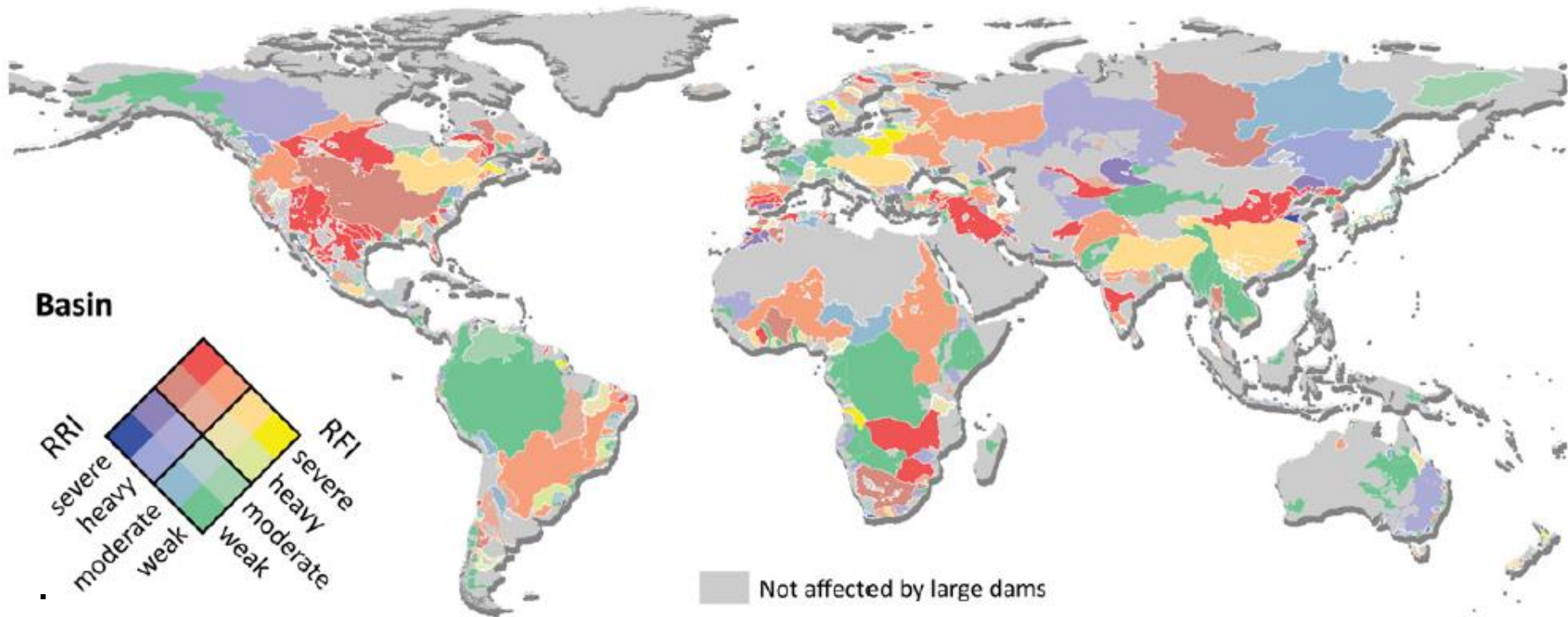
Biodiversity & ecosystem processes

High-head reservoir Emosson (CH)

# Fragmentation & flow regulation

**Increase in fragmentation** (longitudinal interruption in flow, sediment, biota, organic matter, etc.) and **flow regulation** (flood, residual flow, hydropeaking) by dams and hydropower plants

**48% of river volume is moderately to severely impacted** by either flow regulation, fragmentation, or both.



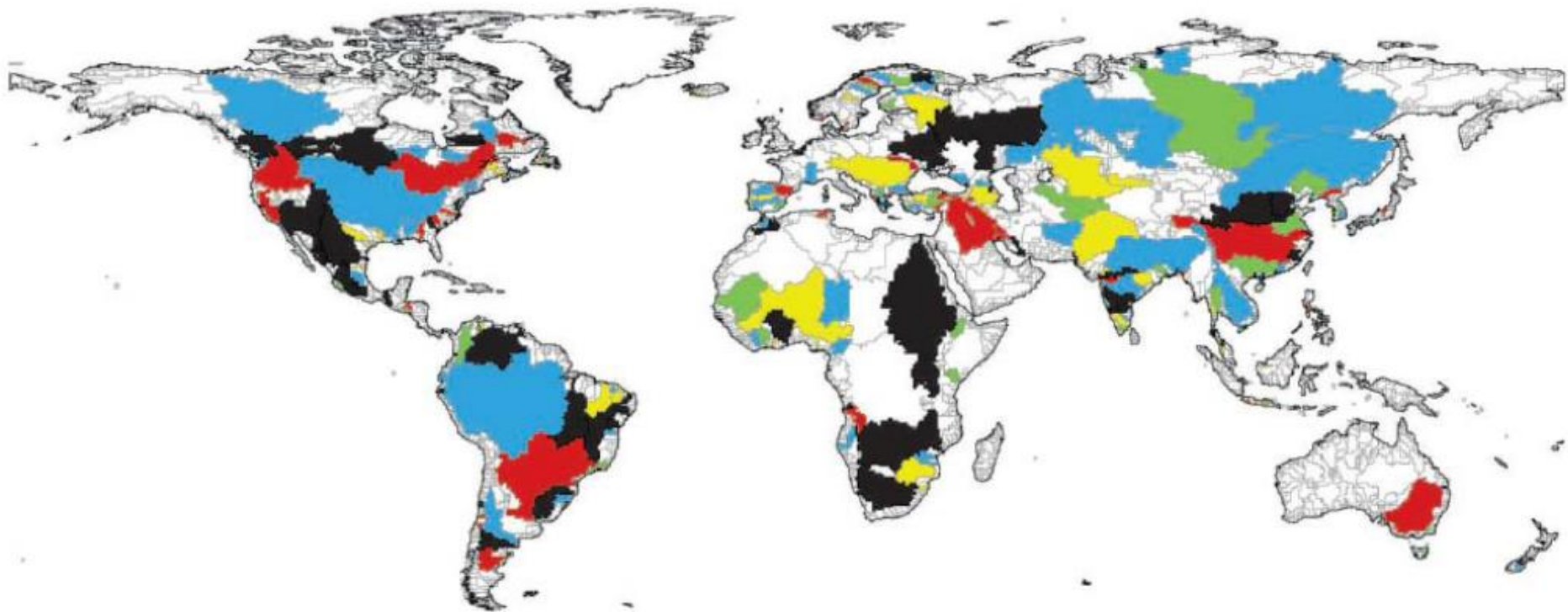
Grill et al. (2015). *Environ. Res. Lett.*



# Bedload

Up to 100% sediment trapping in storage reservoirs and dams

Reduction of bedload and dynamic



Basinwide Trapping Efficiency (%)

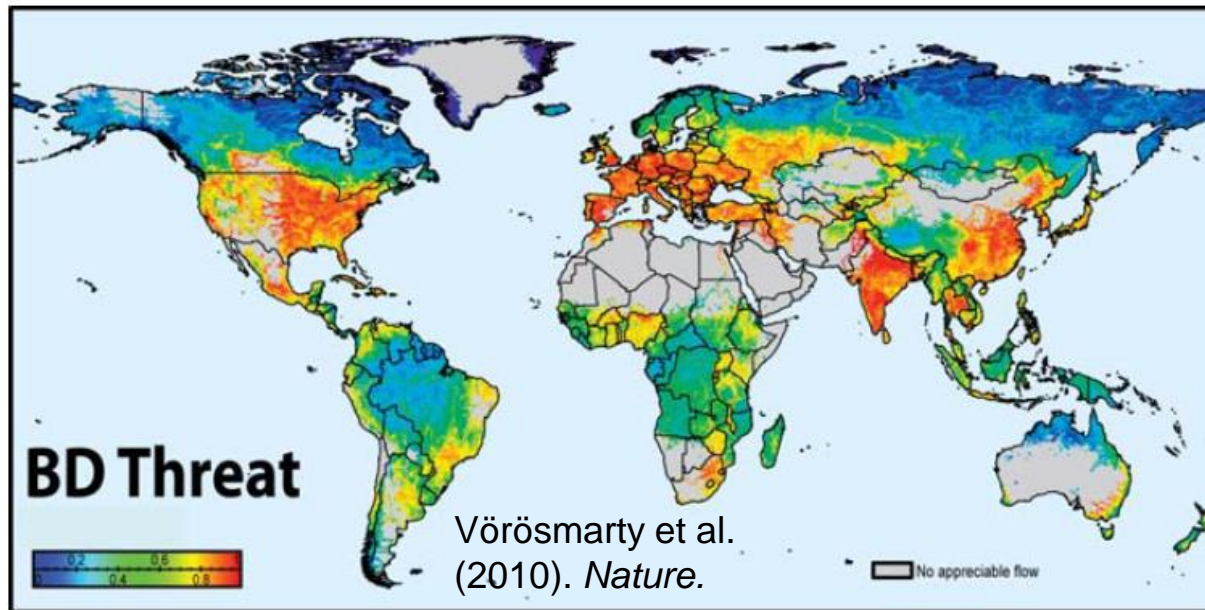


Vörösmarty et al. (2003).  
*Glob. Planet. Change*



# Biodiversity

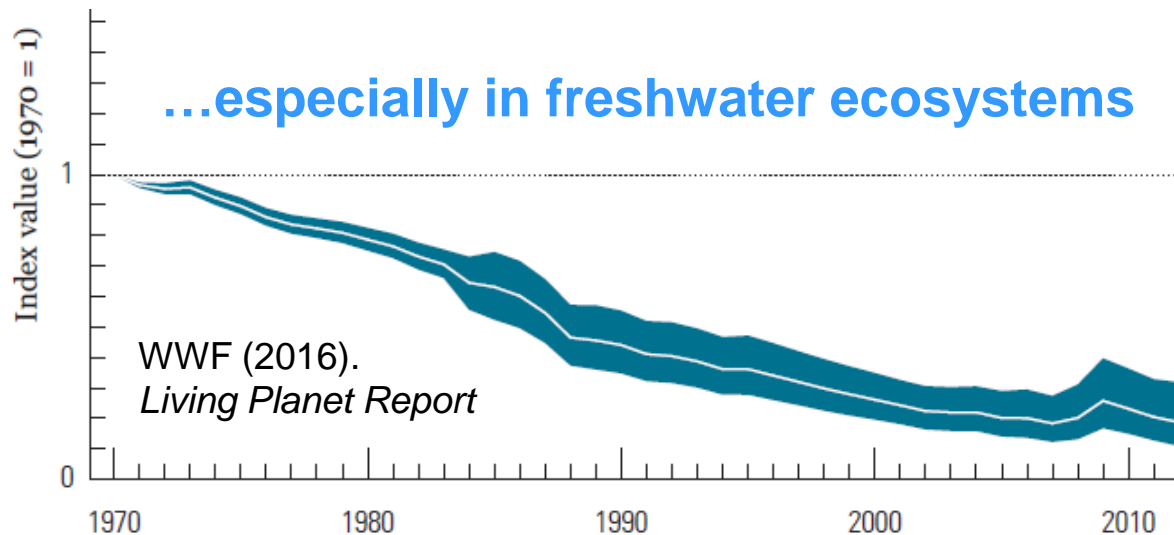
## Biodiversity is strongly endangered



Freshwater accounts for only 0.01% of the world's water (Dudgeon et al., 2006) but provides a habitat for almost 10% of the world's known species (Balian et al., 2008).

Strongest decline in freshwater species like fishes and amphibians: 81% in the last 40 years.

The most common threat to declining populations is habitat loss and degradation.



# **Mitigation of hydropower impacts in Switzerland**

Between ecological & economical  
acceptable solutions

# Actual situation in Switzerland

~ **1300 Hydropower plants**: 13.8 GW capacity & 36 TWh/a production  
(> 90% from the ~ 200 large HPP (> 10 MW))



> **100,000 barriers** higher than 0.5 m -> mean free flowing reach: 650 m  
~ **13,800 km river in bad morphological state** (21% of total river network)



# New Swiss water protection law

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The 2011 changes of the Water Protection Act (WPA) and of the Water Protection Ordinance (WPO) aim to **rehabilitate** the water bodies **(until 2090)** and to **eliminate the negative impacts of hydropower plants (until 2030)** on water bodies.

**Morphological Rehabilitation**  
**Flowing & Standing waters, Alluvial plains**  
(Art. 36a & 38a)

40 Mio. CHF/a  
Federal subsidies

**Hydropeaking**  
(Art. 39a)

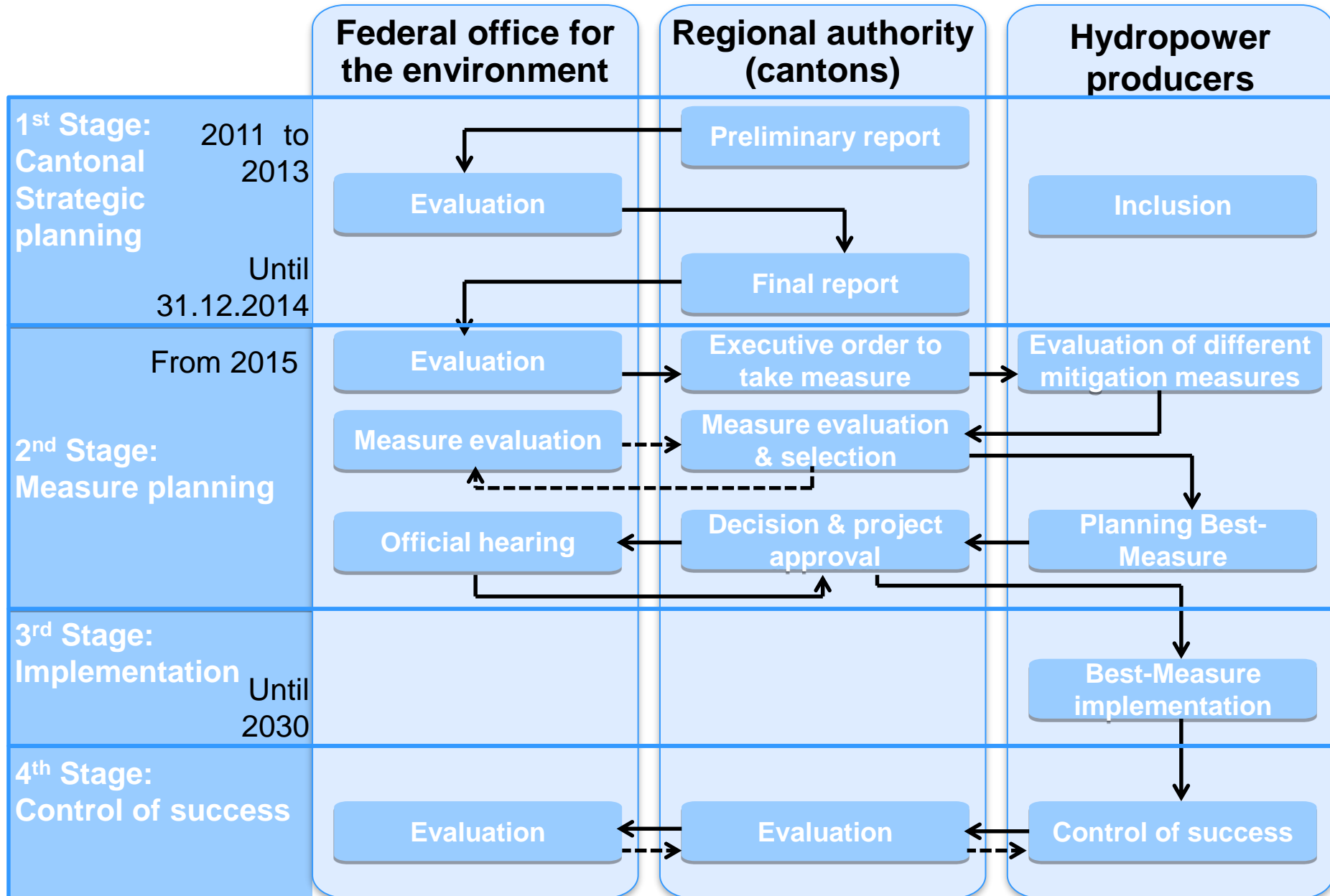
**Bed load budget**  
(Art. 43a)

**Fish migration**  
(Art. 9 & 10 BGF)

50 Mio. CHF/a  
Swissgrid

Similar goals are also sought by the **European Water Framework Directive** (WFD, 2000).

# Political and methodological procedure





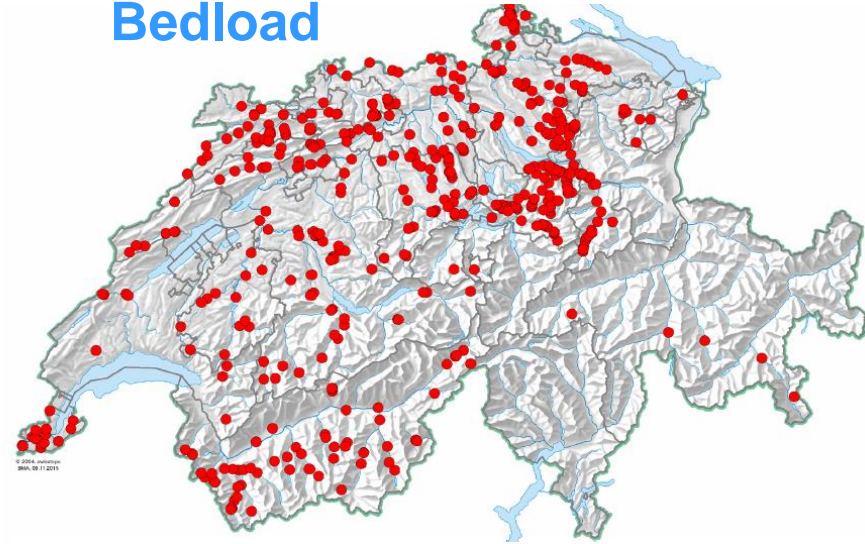
# Identification of large impacts

## Hydropeaking



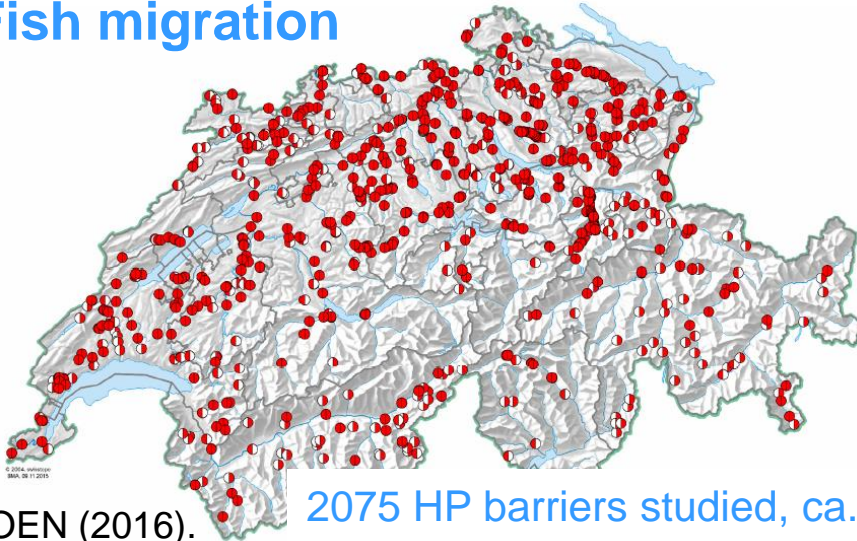
675 HP studied; ca. 100-120 HP need mitigation measures

## Bedload



3500 facilities studied (1000 HP); 495 need mitigation measures (134 HP)

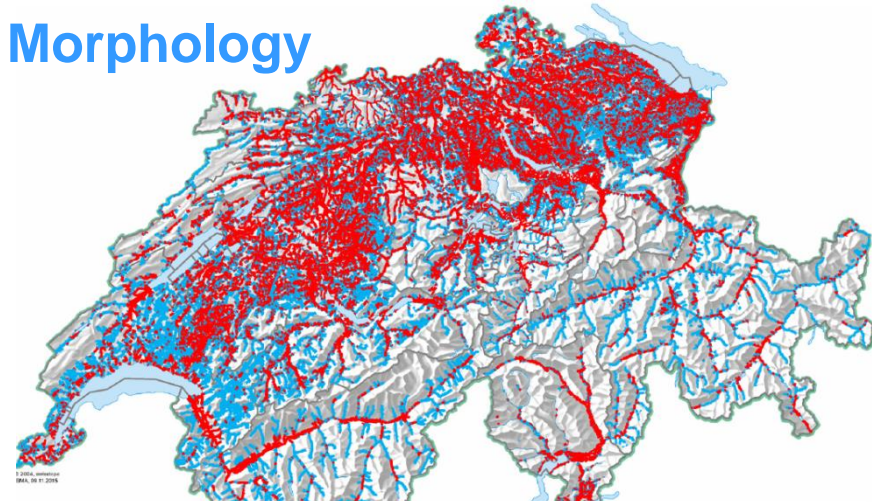
## Fish migration



FOEN (2016).  
Unpublished

2075 HP barriers studied, ca. 1000 need mitigation measures

## Morphology



36,767 km studied, ca. 13,800 km in a bad state, only 4'000 km can be ameliorated



# Mitigation measure: Hydropeaking

Retention basin or cavern for a damped release of turbine water



© Markus Zeh

Tonolla et al. (2017). *Sci. Total Environ.*



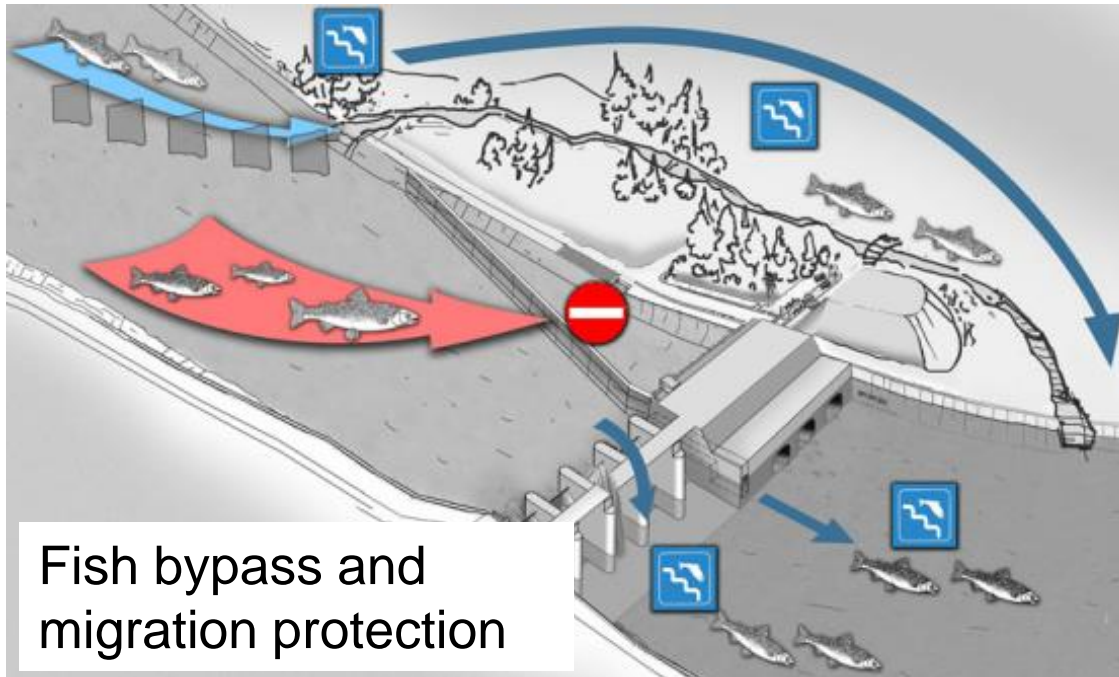
# Mitigation measure: Bedload

Combination of artificial floods and sediment replenishments



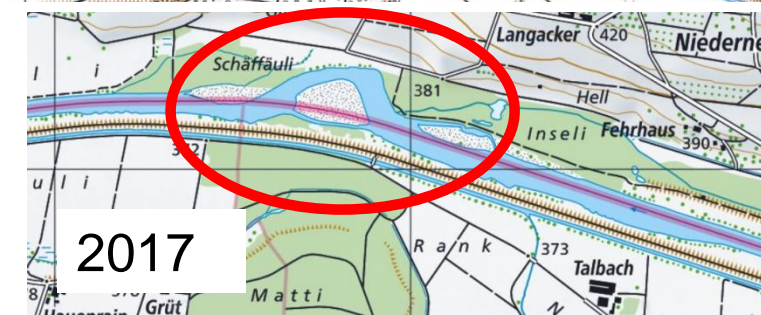
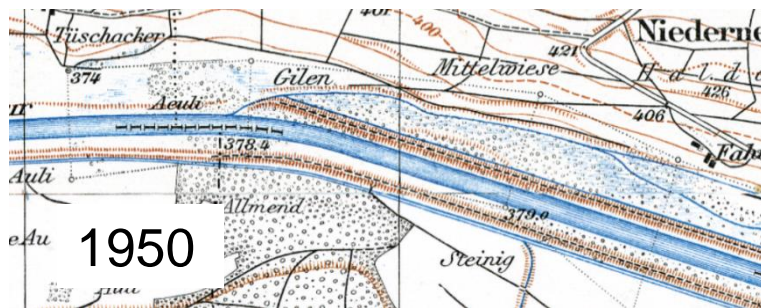


# Mitigation measure: Fish migration





# Mitigation measure: Morphology



Canalization

Dewatering

Urbanisation



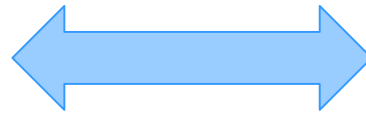
Morphological improvement

# Success and challenges

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## Success

- **Constructive exchange** between scientists, offices, authorities, hydropower companies, and NGOs
- **Guidelines and scientific papers**
- Implementation of **effective measures**
- **Monitoring**
- **Adaptive management**



## Challenges

- Consideration of **all** relevant **stakeholders** interests
- Ongoing **exchange** incl. **basic vs. applied science**
- Implementation into **practice**
- Consideration and evaluation of **all impacts** (also long-term)
- **Coordination** of mitigation measures
- **International exchange**

# Adaptive Management

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Involve  
Stakeholders

**We would be happy to share with you  
our experience & Look forward for  
constructive discussions and joint  
projects!!!**

Learn

Scientific  
Monitoring  
and  
evaluation



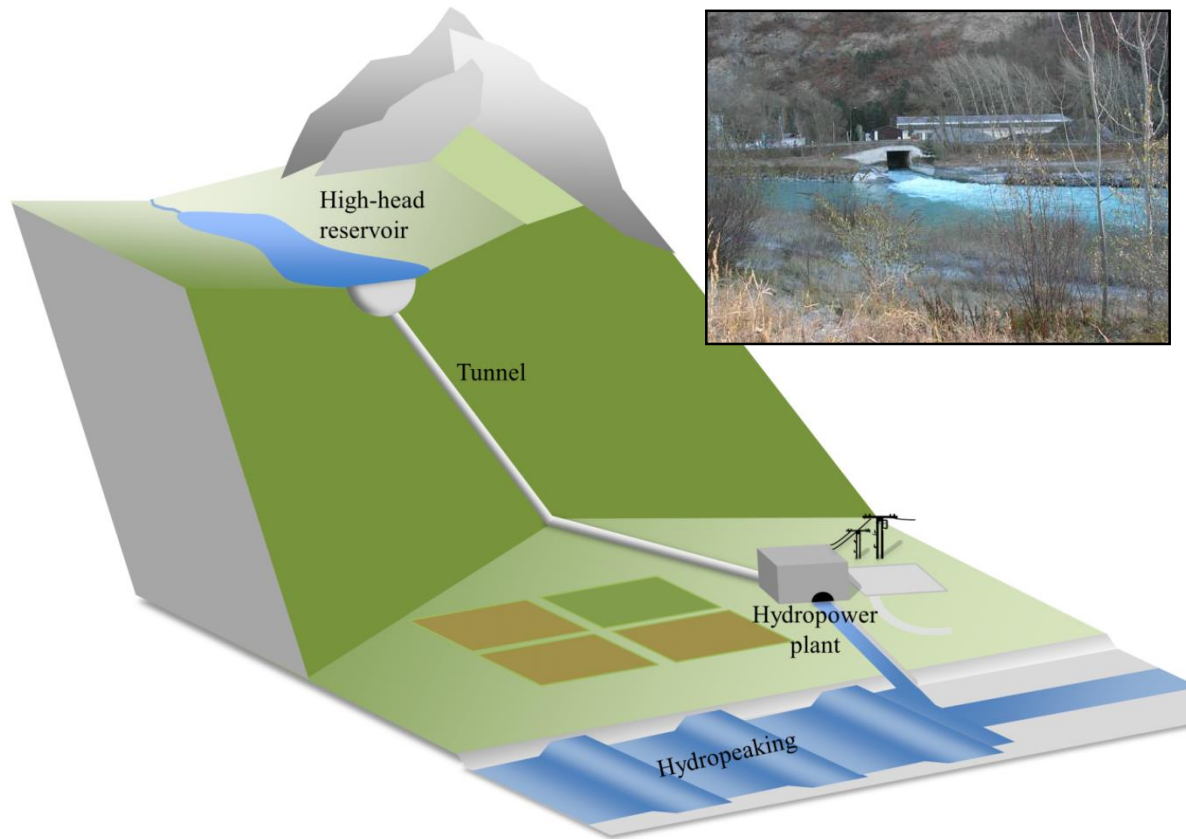


**Many thanks for your attention!!!**

**For more informations: [tono@zhaw.ch](mailto:tono@zhaw.ch)**

# Hydropeaking

**Hydropeaking:** Daily and sub-daily fluctuations in discharge and water levels due to energy demand

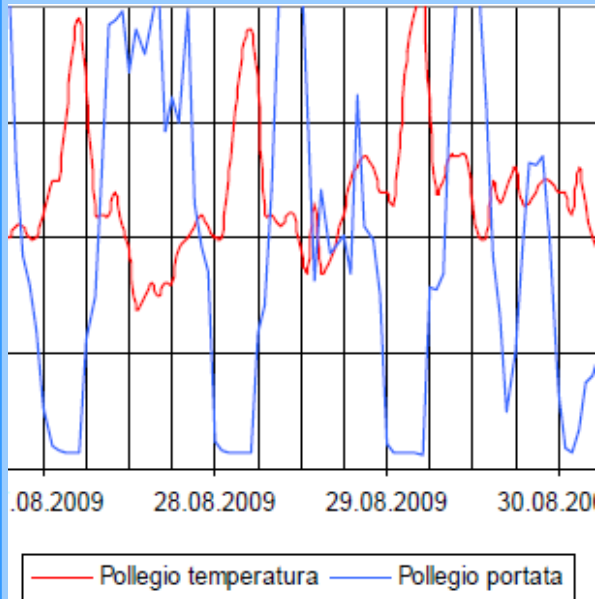


Bruder et al. (2016, *modified*).  
*Sci. Total Environ.*



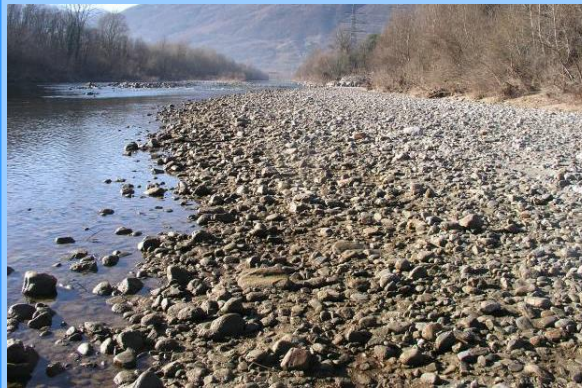
# Possible hydropeaking impacts

## Discharge & Temperature



Unnatural, daily  
fluctuations

## Habitat



Clogging &  
Connectivity

## Organisms



Stranding & Drift

# Possible impacts of bedload deficits

## Habitat



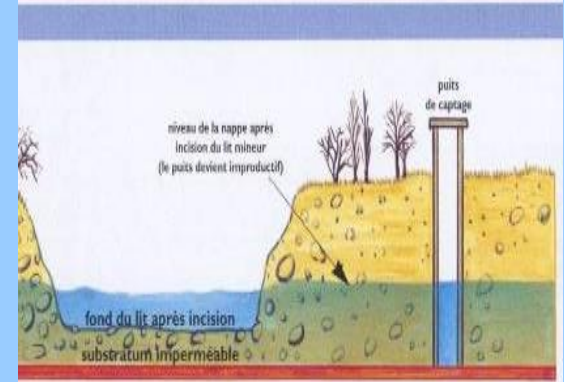
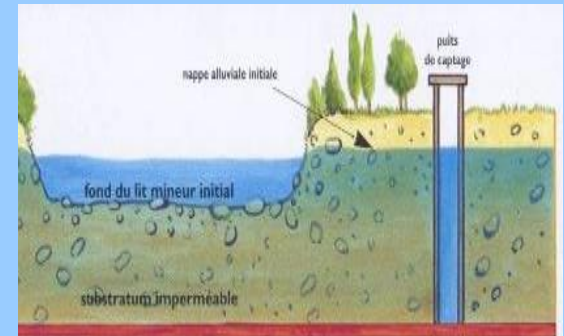
Structure loss &  
Clogging

## Flood protection



Accumulation  
& Erosion

## Groundwater- balance



Channel-bed  
incision



# Possible impacts of hydropower-barriers

## Big tech. facilities



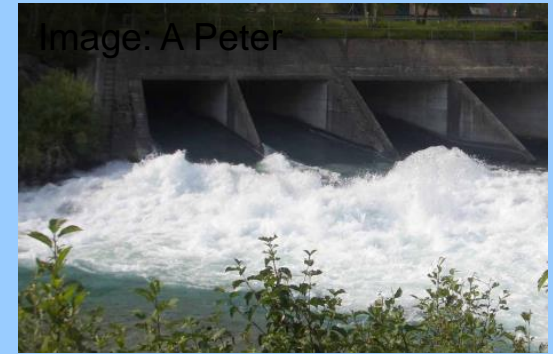
Dam & Weir

## Small techn. facilities



Block ramp &  
Sill

## Hydraulic barriers

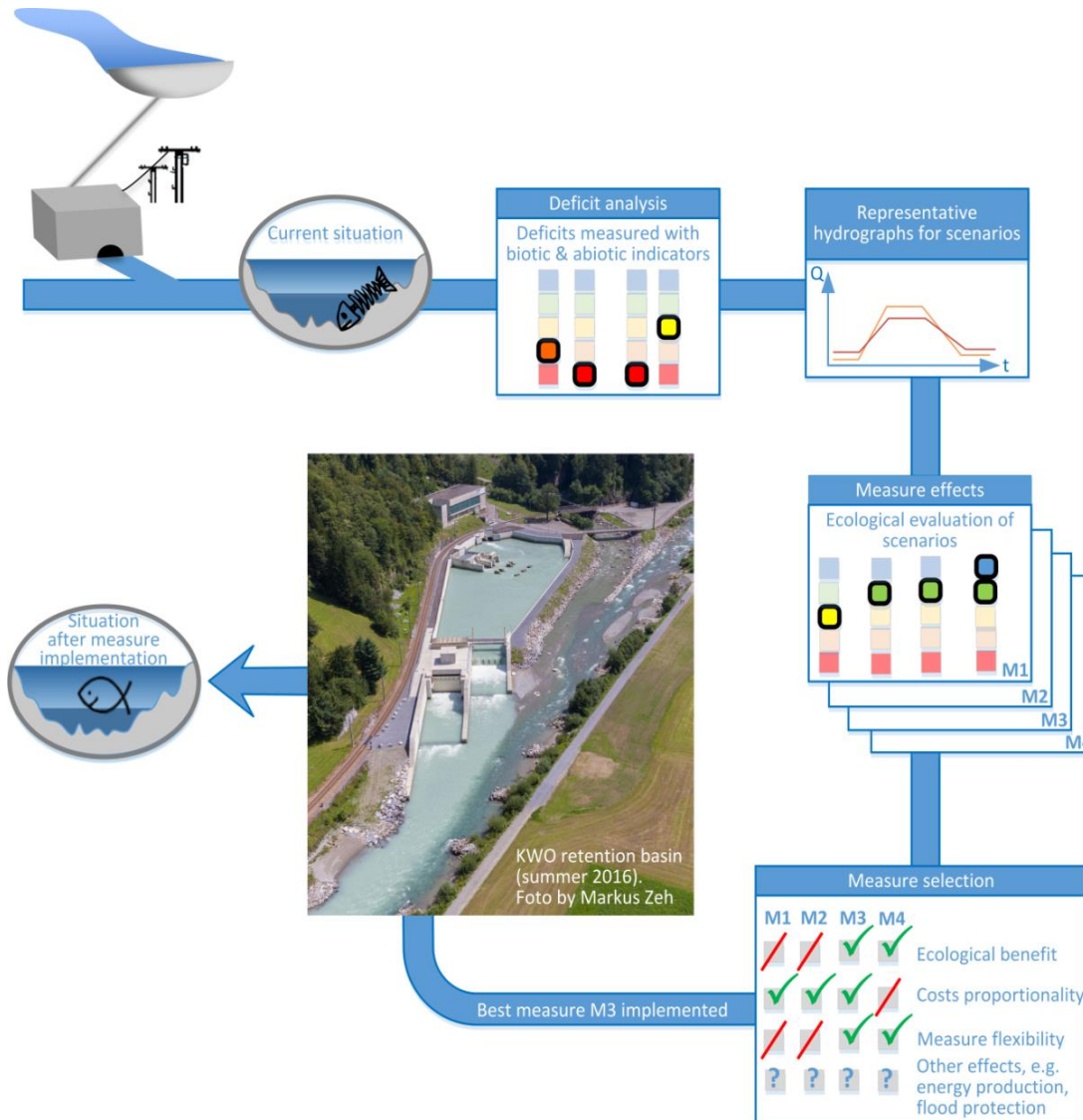


Water outlet &  
Water velocity

# General evaluation method

## Involved stakeholders

- Research institutes
- Environmental & Engineering offices
- Federal & Cantonal authorities
- Hydropower plant
- NGO's
- Landowners
- Fishermen
- Others



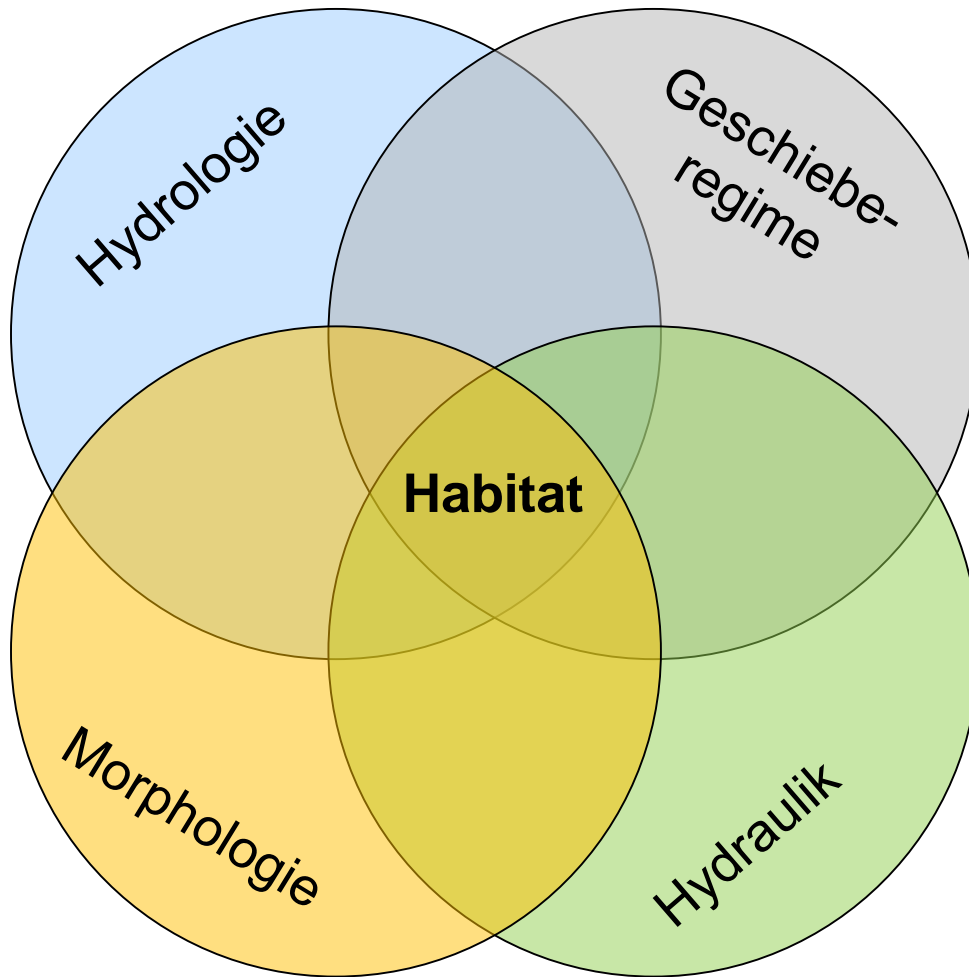
## Main evaluation tools

- Numerical models
- Physical models
- Expert judgments
- *In-situ* experiments
- Cost-benefit analyses



# Allg. physikalische Auswirkungen

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Änderungen von  
Abflussquantität &  
-regime

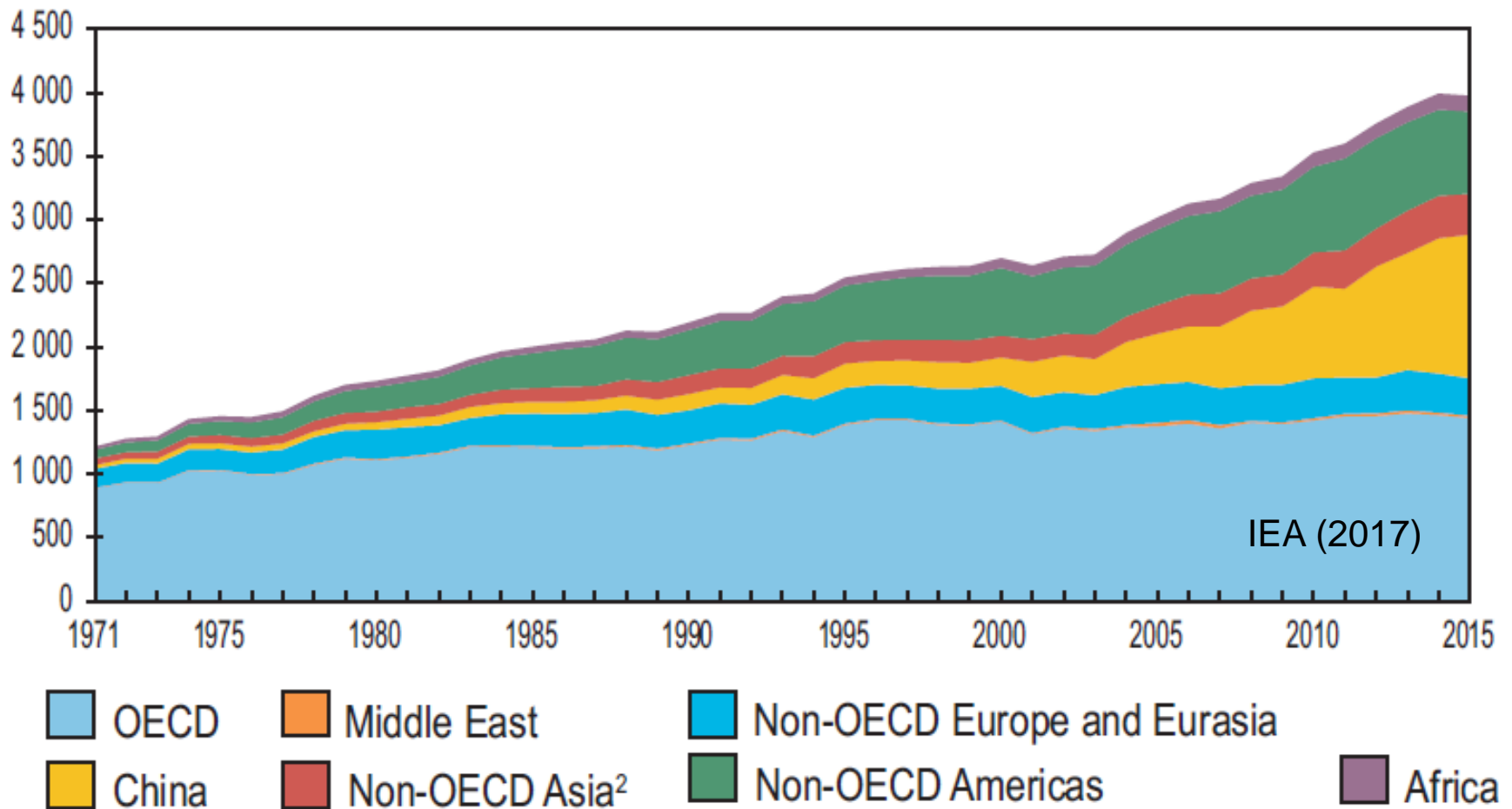
- Hochwasserdynamik
- Restwasser
- Schwall-Sunk

Änderungen von  
Geschiebehaushalt & -  
dynamik

Beeinträchtigung der  
longitudinale & laterale  
Vernetzung

# Importance of hydropower plants

Increase in world hydro electricity production from 1971 to 2015 by region (TWh)



IEA 2017. Key world energy statistics (2015 data). International Energy Agency, Paris.